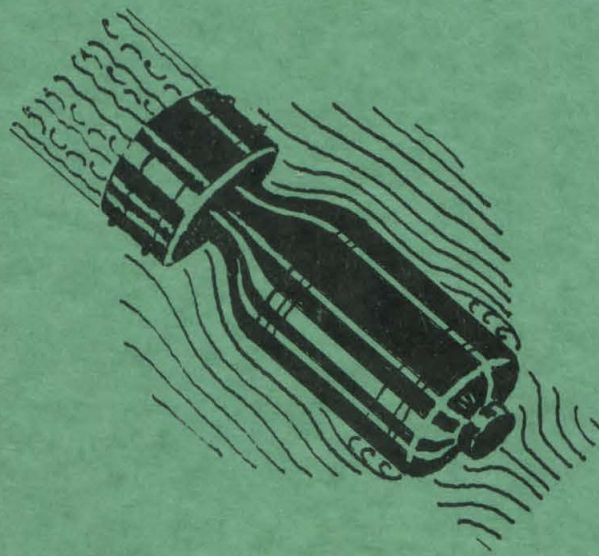


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UNDERWATER CHARACTERISTICS OF PROJECTILE 61.04

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THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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UNDERWATER CHARACTERISTICS
OF
PROJECTILE 61.04

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UNDERWATER CHARACTERISTICS

OF

PROJECTILE 61.04

ABSTRACT

This report covers the underwater performance characteristics of a torpedo shape of the 61 series, designated as Model 61.04. This shape is a modification of Model 61.01, the original form of the 61 series, ⁽¹⁾ the tail fin span being reduced and short runners added to the forward part of the cylindrical section and on the fins. All tests were made on models without propellers.

The characteristics of Projectile 61.04 are compared with those of Projectile 61.01, for yaw (or pitch) angles up to 12 degrees, and for rudder settings up to 20 degrees.

Tests were made, at neutral rudder only, on Projectile 61.04 with the short runners removed from the body and tail fins, to measure the effect of the runners.

These tests were authorized by Dr. E. H. Colpitts, Chief of Section 6.1, NDRC, in his letter of October 8, 1943.

CONCLUSIONS (Refer to Figures 11 and 12)

1. Drag

At zero yaw the drag of Projectile 61.04 (narrow fins) is the same as for Projectile 61.01 (wide fins) for all rudder settings. The drag increases with yaw, the percentage increase being less for Projectile 61.04 than for 61.01 with its wider fin span. At 6° yaw, the increase in drag with neutral rudder is 13% for 61.04 and 21% for 61.01 over the drag at zero yaw. At 6° yaw and 20° rudder, the corresponding increase over 0° yaw and 20° rudder is 27% for 61.04 and 35% for 61.01. With the runners removed, the drag of Projectile 61.04 is about 10% less at neutral rudder than with the runners attached.

(1) Figures in parentheses refer to references listed at the end of this report.

2. Cross Force

The change in cross force per degree change in yaw is much less for Projectile 61.04 than for 61.01. The total change in cross force, at neutral rudder, from -2° to $+2^{\circ}$ yaw, for 61.04 is only half of the corresponding change for 61.01. Close to zero yaw, at neutral rudder, the rate of change of cross force with yaw is very small for both projectiles. At 20° rudder setting and $+4^{\circ}$ yaw, the change in cross force per degree of yaw is about 45% greater for 61.01 than 61.04.

3. Moment

The location of the center of gravity was not given, and all moment coefficients are given about the calculated center of buoyancy, 36.0 inches from tip of the nose, for both Projectiles 61.01 and 61.04.

At neutral rudder, Projectile 61.04 is statically unstable throughout the yaw range tested, $\pm 12^{\circ}$. Projectile 61.01 shows about the same rate of increase in destabilizing moment up to $+1^{\circ}$ yaw, but at $+3^{\circ}$ yaw the rate of change of moment with yaw reverses and the projectile reaches a statically stable condition at about $+11.5^{\circ}$ yaw.

The effect of the rudder in correcting static instability is much less for Projectile 61.04 than for 61.01. For example, Projectile 61.04 with a 10° port rudder setting has a maximum control angle of about 2° starboard yaw, while for the same rudder setting Projectile 61.01 has a control angle greater than 12° yaw, the limit of the tests. As measured by the change in moment coefficient at zero yaw, a 10° rudder setting produces a 17% greater moment change on 61.01 than on 61.04, and a 20° rudder setting a 57% greater change.

4. Maneuverability

No tests were made on either projectile to indicate dynamic stability or the damping coefficient. Qualitatively, however, for underwater running the following conclusions appear justified:

- (a) The mass (including additional apparent mass) of the two projectiles is very nearly the same.
- (b) Due to the smaller fin area, the damping moment is expected to be less for 61.04 than for 61.01.

- (c) The cross force necessary to balance the centrifugal force on a turn of given radius will require a larger yaw for 61.04 than for 61.01.
- (d) At yaws over about 1 to 4 degrees, the destabilizing moment (static) of a 10° to 20° rudder setting in the same direction as the yaw is considerably greater for 61.04 than for 61.01. Consequently, a higher angular velocity (shorter turning radius) will be required for Model 61.04 than for 61.01 in order to develop a damping moment equal to the destabilizing moment.
- (e) Projectile 61.01, due to the greater damping moment and greater static stability can be expected to be less sensitive to accidental perturbations tending to throw it off its course.

It is to be born in mind that the tests were made without propeller, the addition of which would result in greater static stability, but should not affect the comparative performance of the two projectiles.

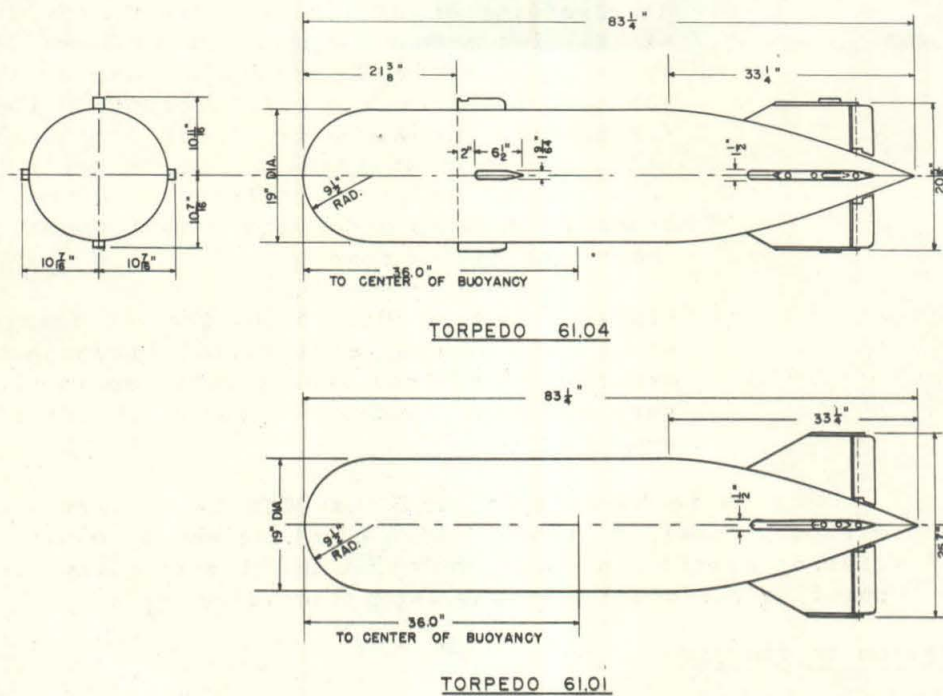
DESCRIPTION OF TORPEDO

Figure 1 shows the shape and principal dimensions of Projectile 61.04 and, for comparison, Projectile 61.01. Figure 2 shows the latter projectile mounted in the tunnel for testing. The spindle shield is shown, but not the image shield.

Figures 3 to 6 are photographs of the models tested, and show the difference between 61.04 and 61.01. Both models are 2 inches in diameter and 8.76 inches long overall. The scale ratio of model to prototype is 1 to 9.5.

The torpedo body has the surface of a solid of revolution. The four fins, each with a rudder, are identical and 90° apart. Either set of rudders may be considered as vertical for yaw control and the other set as horizontal for pitch control.

Figures 7 and 8 show, for comparison, the details of the rudder and fin construction of both Projectiles 61.04 and 61.01.



OUTLINE DIMENSIONS OF TORPEDOS
61.01 AND 61.04

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FIGURE 1

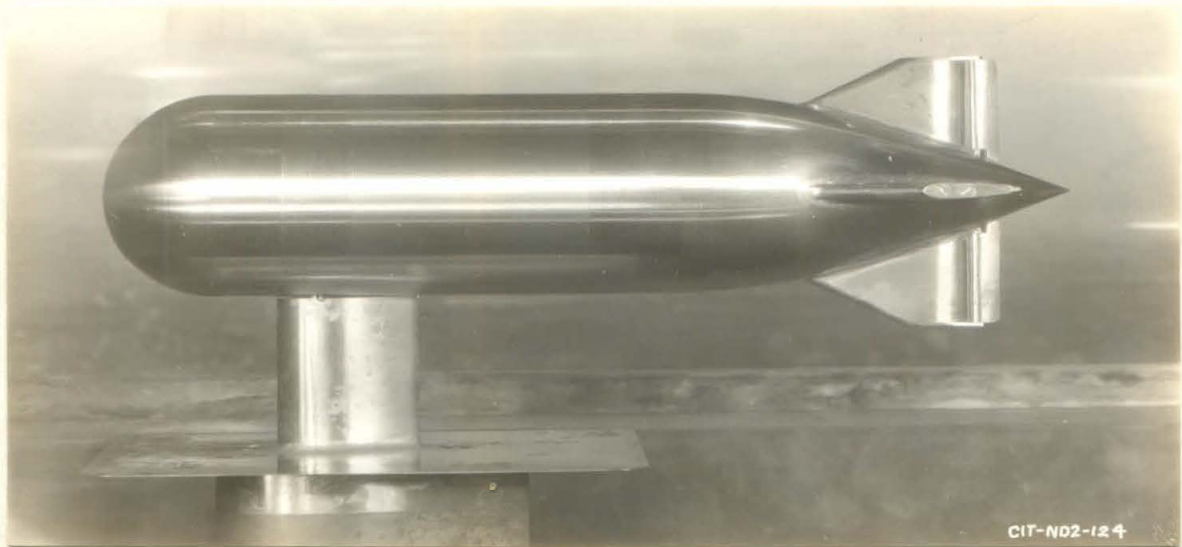


FIGURE 2
MODEL MOUNTED IN THE WATER TUNNEL



FIGURE 3
TORPEDO MODEL 61.04, SIDE VIEW

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FIGURE 4
TORPEDO MODEL 61.04, REAR VIEW



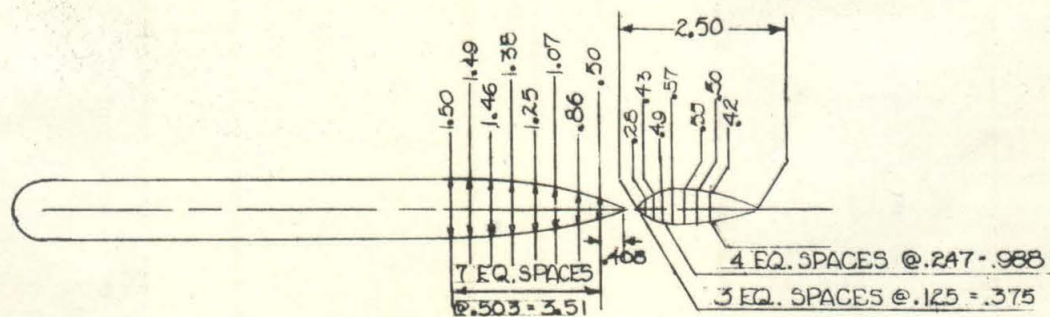
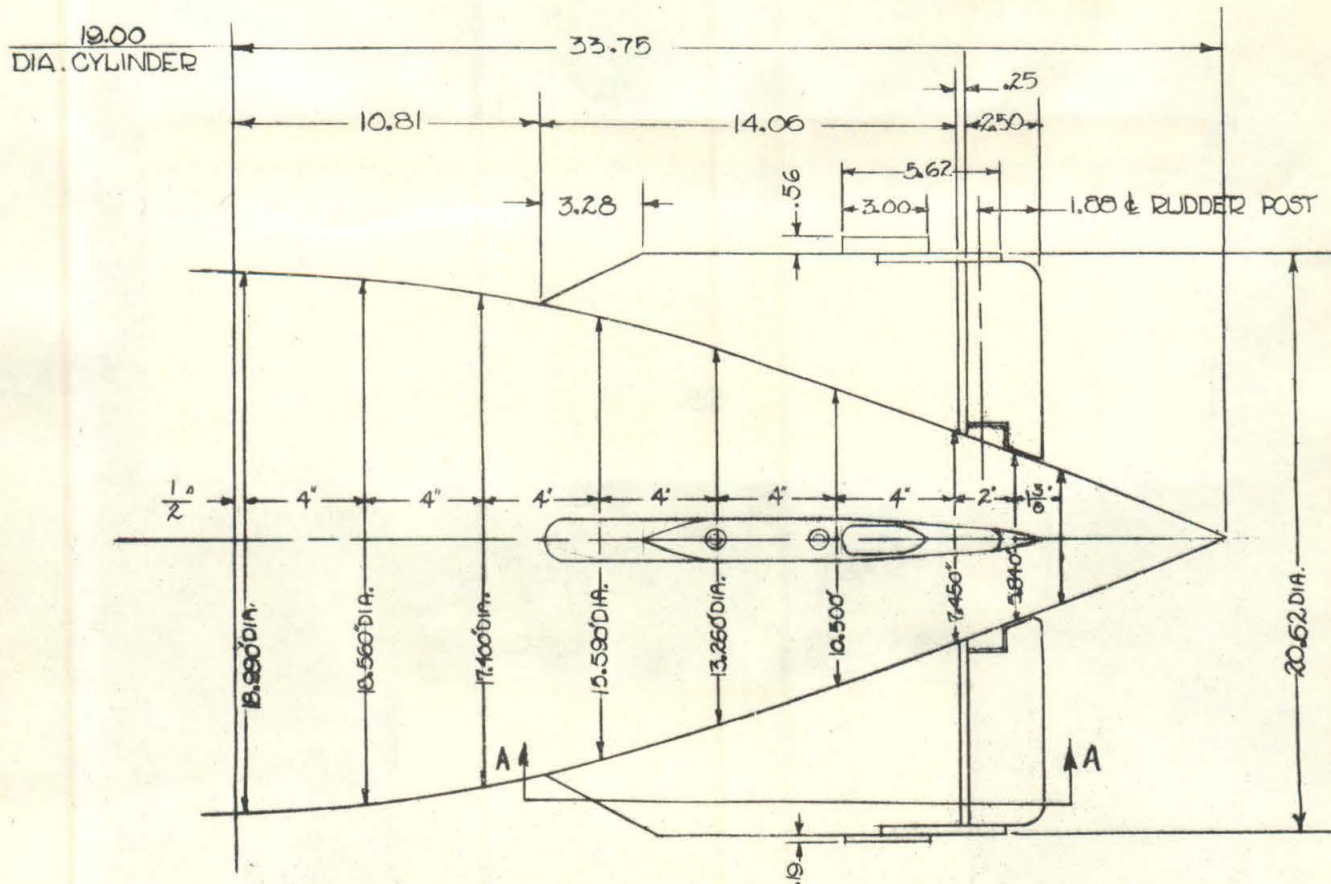
FIGURE 5
TORPEDO MODEL 61.01, SIDE VIEW

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FIGURE 6
TORPEDO MODEL 61.01, REAR VIEW

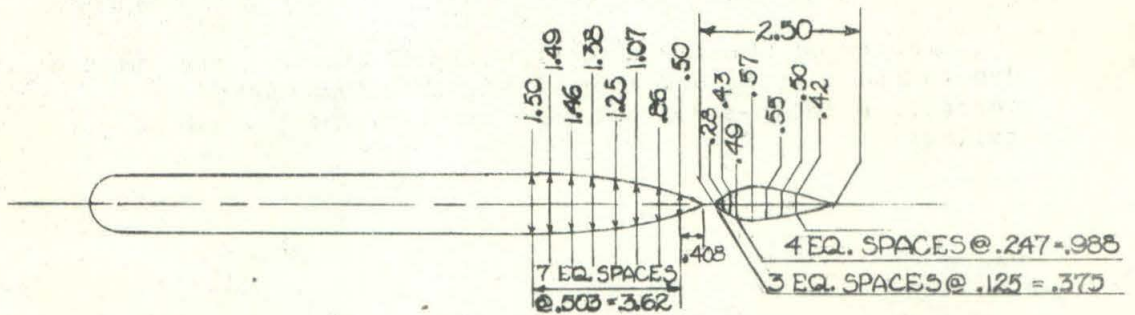
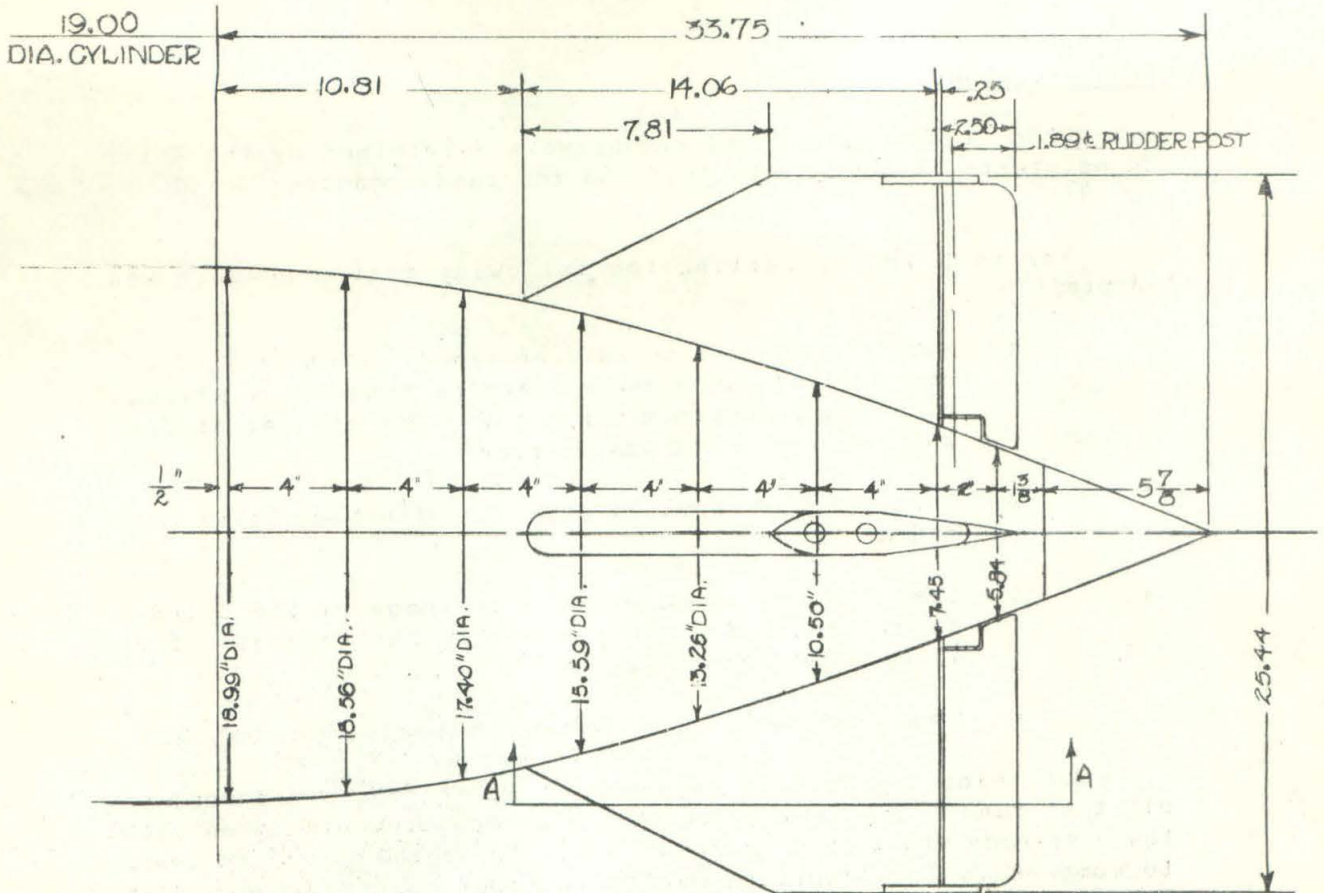
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AFTERBODY
MODEL N^o 61.04

FIGURE 7

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SECTION A-A (ENLARGED)

AFTERBODY
MODEL N^o 61.01

TEST PROCEDURE

Drag, cross force, and moment were determined by the Water Tunnel tests at yaws up to $\pm 12^\circ$ and for rudder angles from 0° to 20° . (2)

For each rudder setting the following test procedure was adopted:

1. With the support spindle shielded, as shown in Figure 2, tests were made over the range from maximum plus yaw to maximum minus yaw, with one set of fins and rudders in the yawing plane.
2. Test (1) was repeated with the afterbody, fins, and rudders rotated 180° .
3. Test (2) was repeated with an image of the spindle shield mounted above the model, but separated from it by a very small gap.
4. Test (1) was repeated with the image shield.

The velocity was held constant at $31.8 \pm$ feet per second in all test runs. The average of the force measurements taken with the afterbody index at 0° and 180° relative to the yaw plane tends to compensate for slight asymmetry in model construction and in the flow in the Water Tunnel.

The image shield correction compensates for the interference due to the support and support shield. The method of making the correction follows the standard wind tunnel procedure and is as follows:

$$F = F_o - (F_I - F_o)$$

where

F is the true force or moment

F_o is the measured force or moment without the image shield

F_I is the measured force or moment with the image shield

The coefficient curves were calculated from the force curves after making the image shield corrections.

Figures 9 and 10 are typical plots of the observed forces and moments on the two models at 10° port rudder setting obtained without the image shield.

~~SECRET~~FORCE MEASUREMENTS

Figures 11 and 12 show the final coefficient curves for 0° to 20° port rudder settings and yaws from 12° port to 12° starboard.

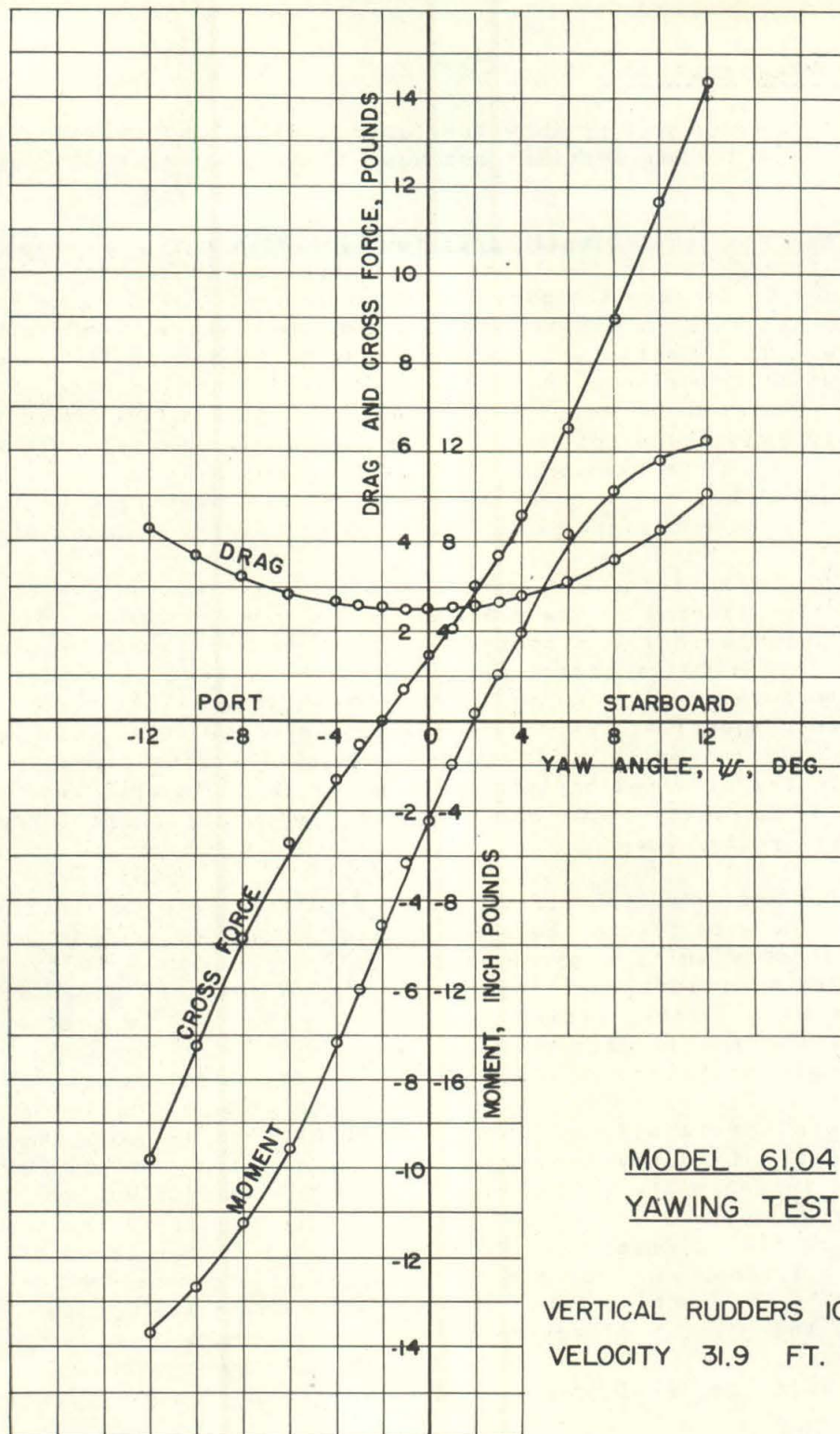
The drag coefficients apply to the models only, and have not been extrapolated to the prototype dimension and speeds. Models 61.04 and 61.01 show the same drag at zero yaw. Model 61.04 without runners shows a 10% decrease in drag over the same model with runners. It appears that the increased form drag of the runners of Model 61.04 offsets the increase in skin friction drag on the larger fins of Model 61.01. Since the form drag of the runners is probably independent of Reynolds number, while the skin friction drag of the tail fins will probably decrease with increasing Reynolds number, it can be expected that the prototype of Model 61.04 will have a higher drag than the prototype of Model 61.01.

The cross force and moment coefficients are probably not materially affected by the model scale and are, therefore, directly applicable to the prototype. The slope of the cross force curves for 61.04 is less than for 61.01. At neutral rudder and close to zero yaw, the cross force changes very slightly with yaw for both projectiles. Apparently, near zero yaw, the cross force on the body is small. With increasing yaw the fins are more exposed to the flow and an increasing cross force is expected. The larger fin area of 61.01 accounts for the larger cross force of 61.01 at greater yaws.

In considering the effect of the rudders on static stability, either in yaw or pitch, the term "control angle" is used to denote the yaw below which a given rudder setting opposite to the yaw will tend to return the projectile to zero yaw, and above which the yaw will further increase. The control angle is useful for indicating the effectiveness of the rudders, and for comparing the static stability of different projectiles at equal rudder settings. For example, in Figure 11 the moment acting on the 61.04 projectile with 10° port rudder setting is negative and opposes the tendency to yaw up to 2° starboard. Beyond 2° it acts to increase the yaw. Thus for this 10° rudder setting, the control angle is 2° . On the other hand, in Figure 12 the moment acting on the 61.01 projectile with 10° port rudder is negative, opposing further yaw, for the entire range of starboard yaw angles covered by the tests. This large increase in control angle shows clearly the greater effectiveness of the larger fins and rudders on the 61.01 projectile. Comparison of the moment curves for 20° rudder settings in Figures 11 and 12 emphasizes this difference.

The moment curves of both models show marked irregularity, particularly at the higher rudder angles. This irregularity was noticed on the tests of all torpedo models with this same type of rudder and fin construction, and repeated measurements at the same

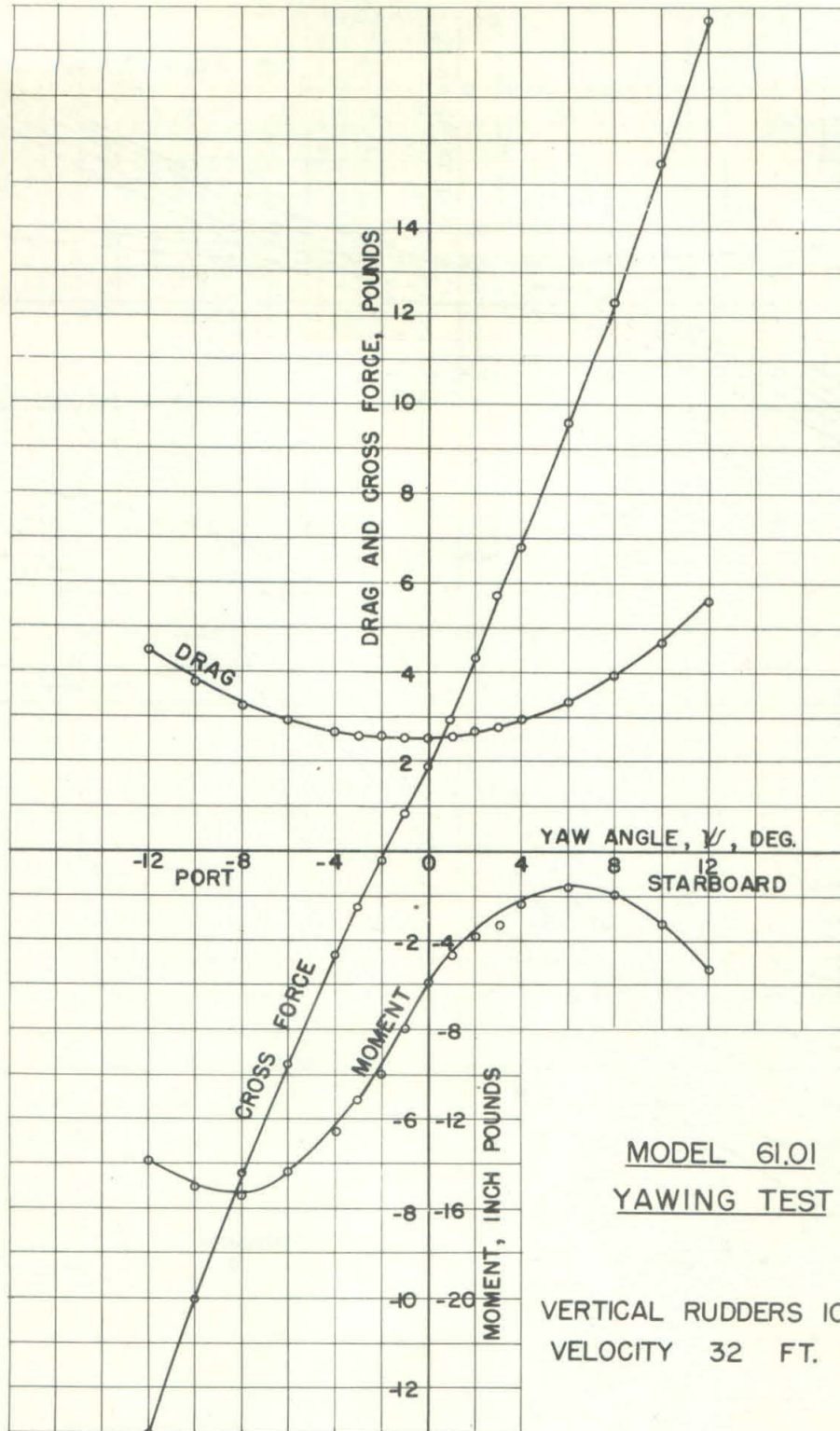
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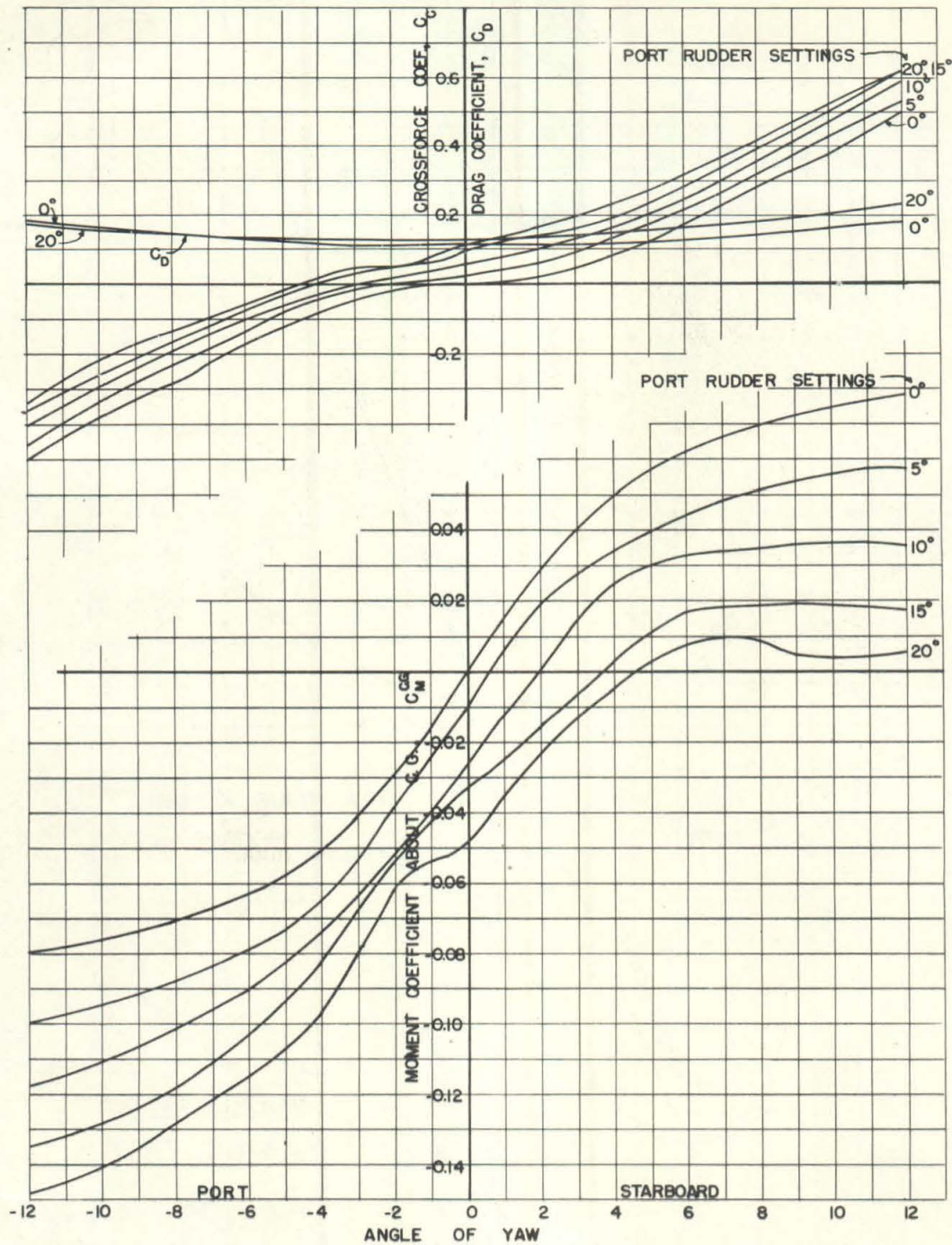
PLOT OF OBSERVED FORCES AND MOMENTS, WITHOUT IMAGE SHIELD
MODEL SUPPORTED AT A DISTANCE OF 3.7" FROM TIP OF NOSE

FIGURE 9

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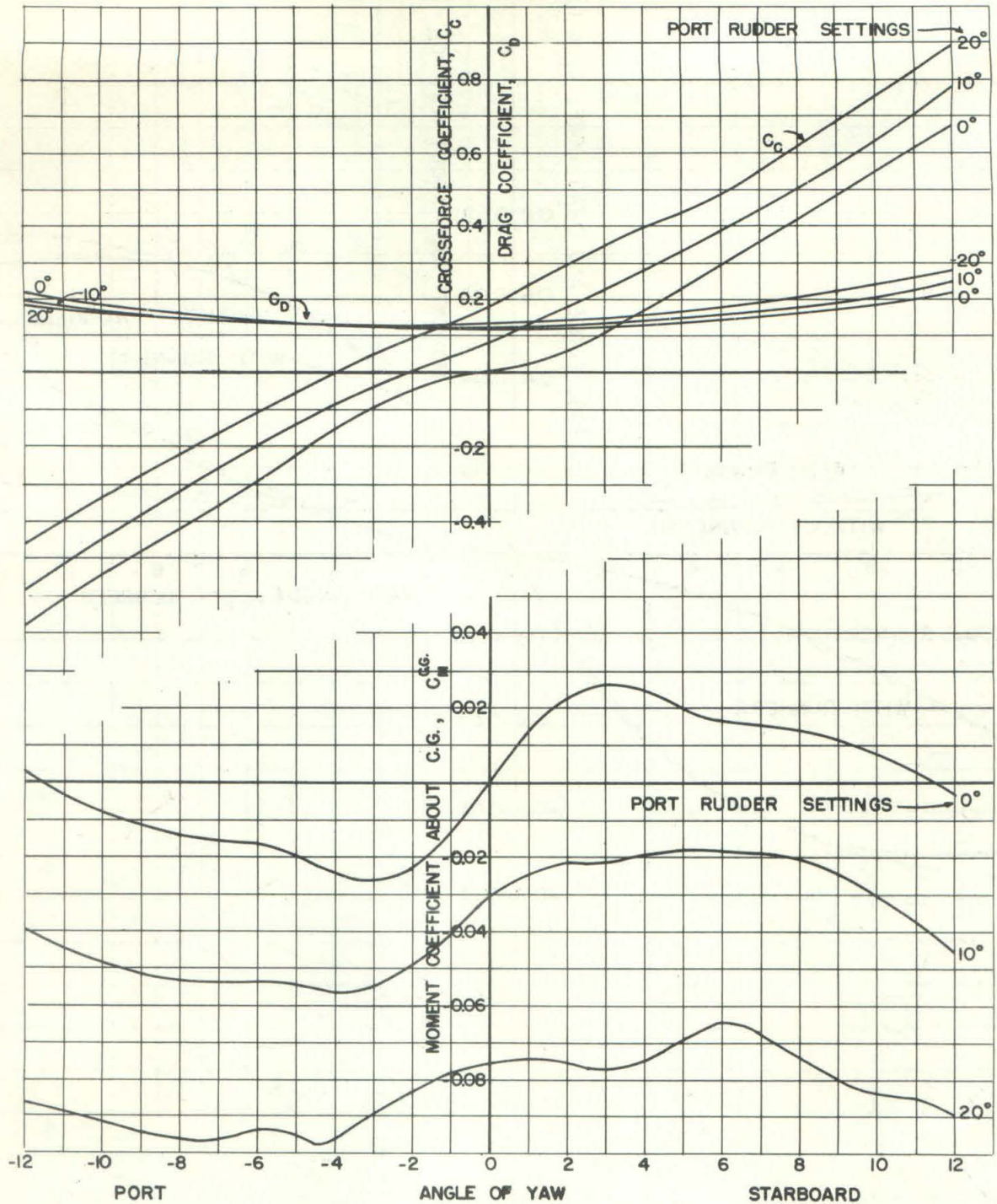
PLOT OF OBSERVED FORCES AND MOMENTS, WITHOUT IMAGE SHIELD
MODEL SUPPORTED AT A DISTANCE OF 3.7" FROM TIP OF NOSE



MODEL 61.04

CROSS FORCE, DRAG AND MOMENT COEFFICIENTS
FOR VARIOUS SETTINGS OF VERTICAL RUDDERS
HORIZONTAL RUDDERS NEUTRAL

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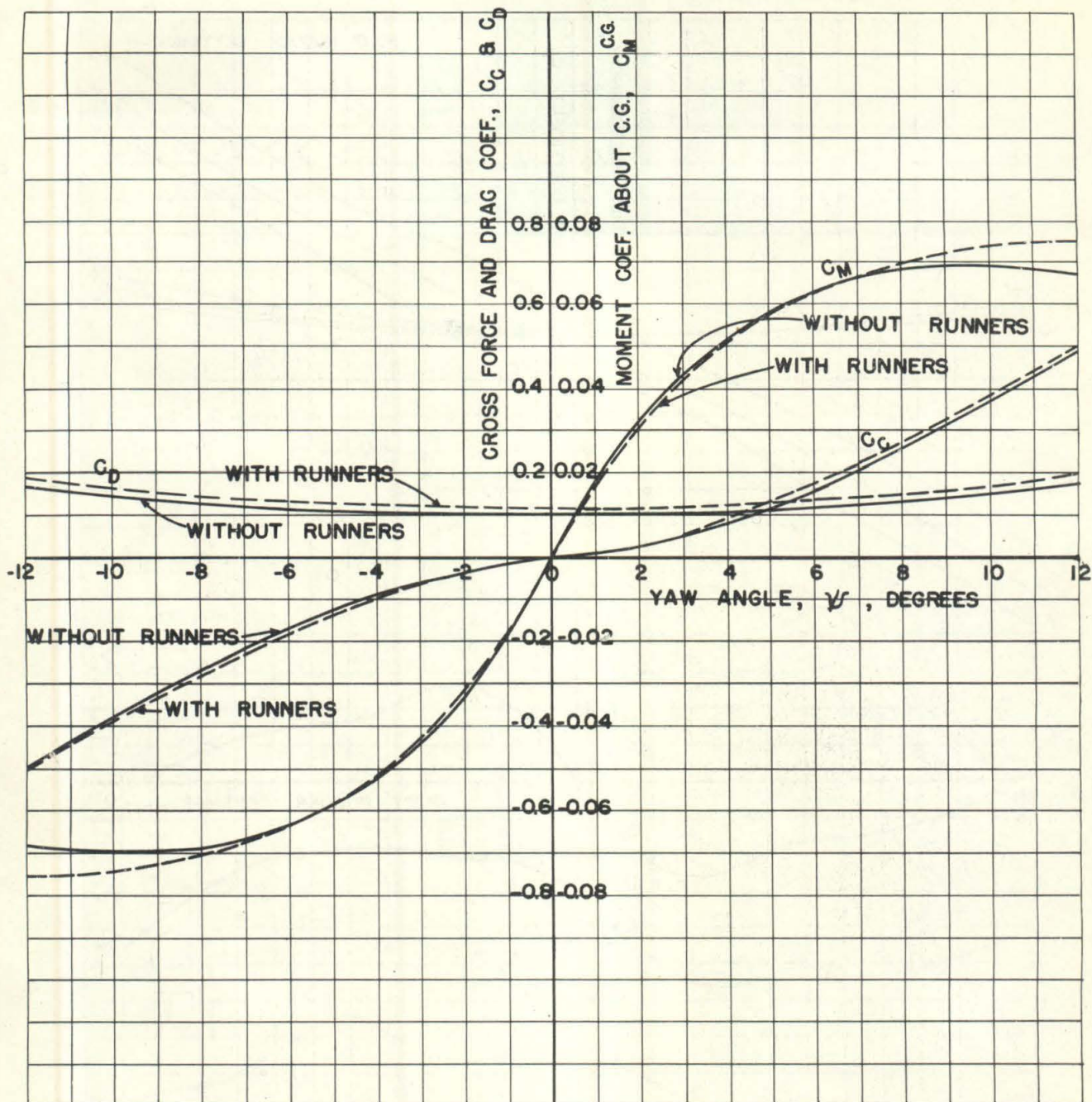


MODEL 61.01

CROSS FORCE, DRAG AND MOMENT COEFFICIENTS
FOR VARIOUS SETTINGS OF VERTICAL RUDDERS
HORIZONTAL RUDDERS NEUTRAL

FIGURE 12

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ND 8-3747 M



MODEL 61.04

COMPARISON OF FORCE AND MOMENT
COEFFICIENTS, WITH AND WITHOUT
RUNNERS.

FIGURE 13

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ND 8 - 2980M

yaw and rudder setting were not very consistent. The curves of Figures 11 and 12 were obtained from the average of repeated measurements.

Flow line observations in the Polarized Light Flume (Figures 16 and 17) show an irregular cross flow through the gap between the rudder and the fixed fin which may account for the moment fluctuations. Figure 18 shows a suggested method of reducing the clearance between the fin and rudder and thus cutting down the flow through the gap.

Figure 13 shows the effect on the drag, cross force, and moment of the runners added on Model 61.04 to fit it into a 21-inch torpedo tube. As noted above, the runners increase the drag about 10% at zero yaw. The effect of the runners on cross force and moment is small.

Observations of the flow pattern around Model 61.04 were made in the Polarized Light Flume. The fluid in the flume has asymmetrical physical and optical properties which permit observation of the flow lines when viewed through polarizing plates. The velocities in the flume are below the range of the Water Tunnel experiments and the patterns can be considered only qualitative.

Figures 14 and 15 show the flow pattern at zero yaw and zero rudder setting. The eddies in the vicinity of the runners indicate additional drag, which is quantitatively confirmed by the drag coefficient curves of Figure 13.

Figures 16 and 17 show in more detail the flow pattern in the vicinity of the rudders at 20° rudder setting. The flow through the gap between the rudder and the fixed fin is clearly indicated.

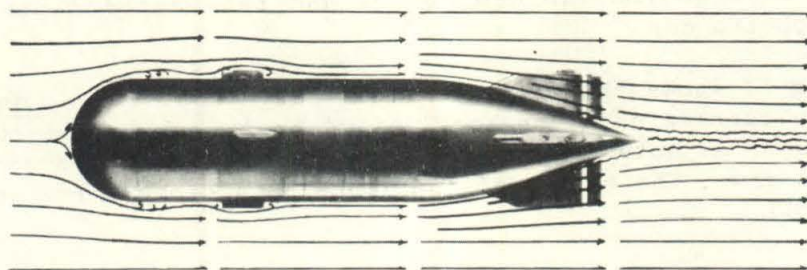


FIGURE 14
MODEL 61.04; OBSERVED FLOW LINES AT ZERO YAW

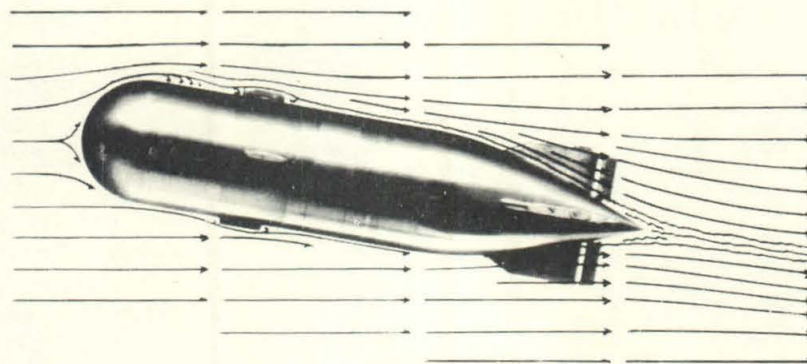


FIGURE 15
MODEL 61.04; OBSERVED FLOW LINES AT 10° YAW

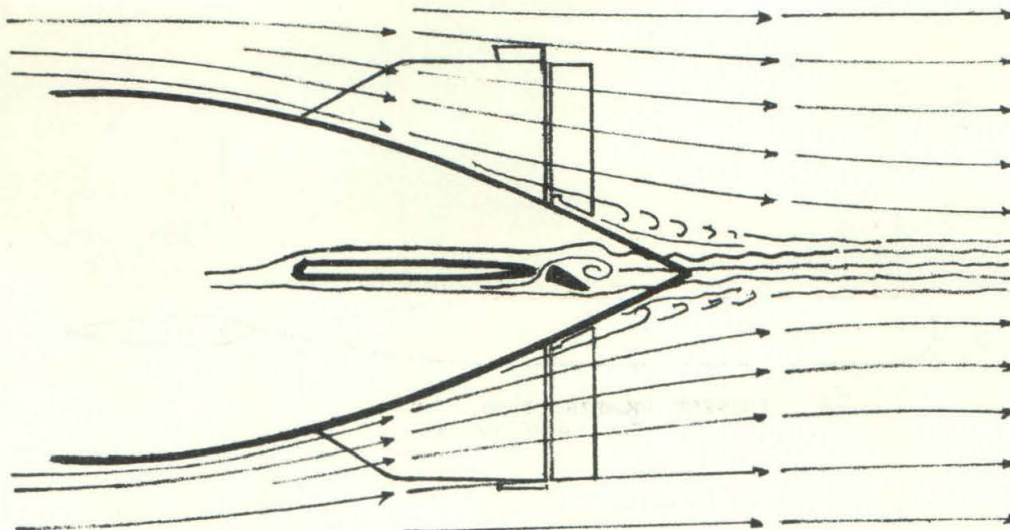


FIGURE 16
MODEL 61.04; OBSERVED FLOW LINES NEAR RUDDER
ZERO YAW, 20° RUDDER SETTING

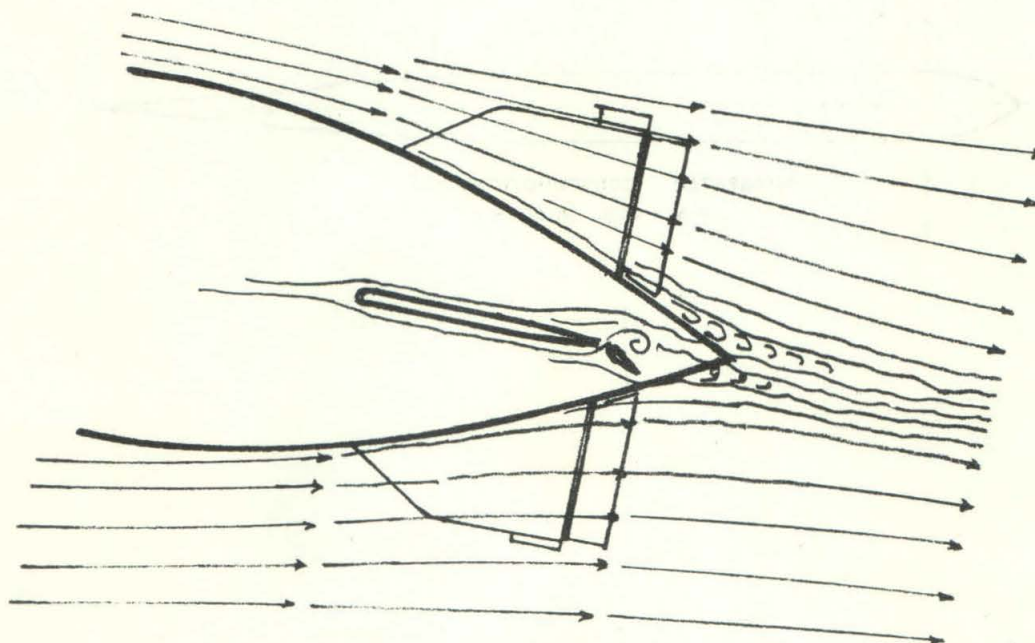


FIGURE 17
MODEL 61.04; OBSERVED FLOW LINES NEAR RUDDERS
 10° YAW; 20° RUDDER SETTING

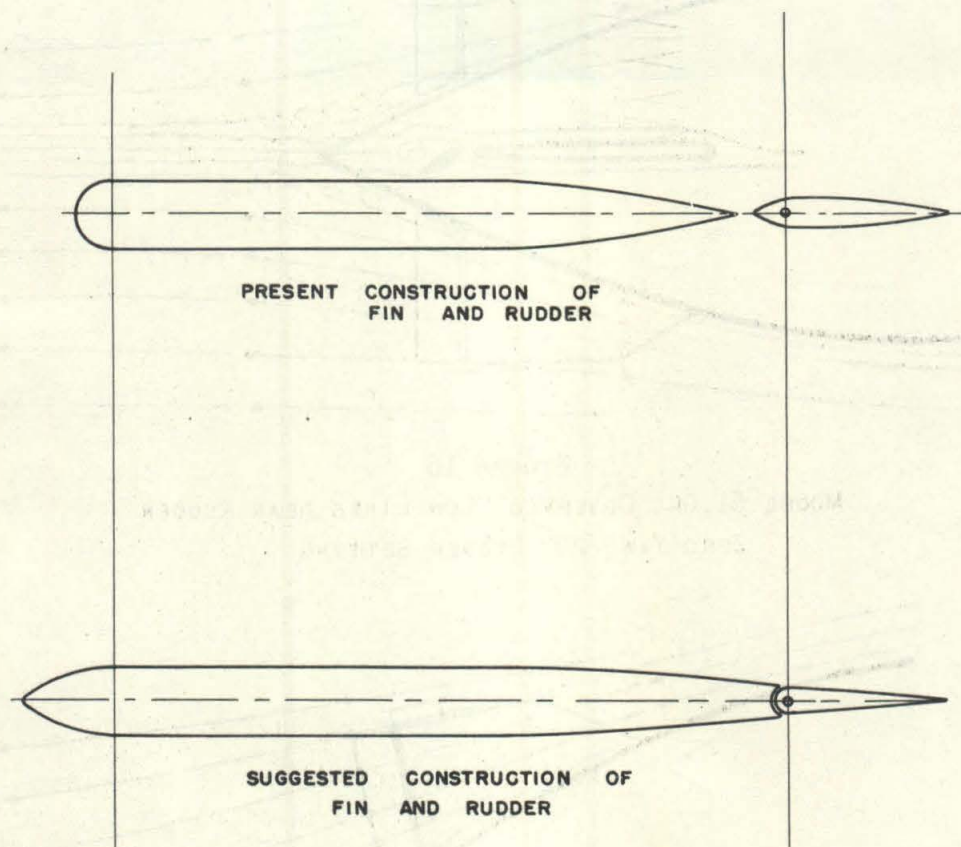


FIGURE 18

REFERENCES:

- (1) "Underwater Performance Characteristics of Projectiles 61.O4 and 61.O3," Section No. 6.1-sr207-1645, June 29, 1944.
- (2) "The High Speed Water Tunnel at the California Institute of Technology," June 29, 1942.

APPENDIX A

DEFINITIONS

PITCH ANGLE

The angle in the vertical plane which the axis of the projectile makes with the direction of travel. Pitch angles are positive (+) when the nose is up, and negative (-) when the nose is down.

YAW ANGLE

The angle in the horizontal plane which the axis of the projectile makes with the direction of travel. Looking down on the projectile and in the direction of travel, yaw angles to the right are positive (+), and to the left, negative (-).

LIFT

The force, in pounds, exerted on the projectile in a direction normal to the line of travel and in the vertical plane, positive (+) when acting upward, and negative (-) when acting downward.

CROSS FORCE

The force, in pounds, exerted on the projectile in a direction normal to the line of travel and in the horizontal plane. A positive cross force is defined as one acting in the same direction as the displacement of the projectile nose for a positive yaw angle.

DRAG

The force, in pounds, exerted on the projectile in a direction parallel with the line of travel. The drag is positive when acting in a direction opposite to the direction of travel.

MOMENT

The torque tending to rotate the projectile about a transverse axis. A positive or clockwise moment tends to increase a positive yaw or pitch angle. A moment, therefore, has a destabilizing effect when it has the same sign as the yaw or pitch angle, and a stabilizing effect when of opposite sign.

COEFFICIENTS

The force and moment coefficients are defined as follows:

$$\text{Lift Coefficient, } C_L = \frac{L}{1/2 \rho V^2 A}$$

$$\text{Cross Force Coefficient, } C_C = \frac{C}{1/2 \rho V^2 A}$$

$$\text{Drag Coefficient, } C_D = \frac{D}{1/2 \rho V^2 A}$$

$$\text{Moment Coefficient, } C_M = \frac{M}{1/2 \rho V^2 A l}$$

where

L = lift force, pounds

C = cross force, pounds

D = drag force, pounds

M = moment, foot-pounds

ρ = density of water, slugs per cu.ft.

V = velocity, feet per second

A = area of a cross section taken normal to the longitudinal axis of the projectile at its maximum diameter, square feet

l = overall length of projectile, feet

REYNOLDS NUMBER

$$R_e = \frac{V l \rho}{\mu} = \frac{V l}{\nu}$$

where

V, l, and ρ are as defined above, and

μ = absolute viscosity of water, pound-second per square foot

$\nu = \frac{\mu}{\rho}$ = kinematic viscosity of water, square feet per second

CAVITATION PARAMETER

$$K = \frac{P - P_v}{1/2 \rho V^2}$$

where

ρ and V are as defined above, and

P = absolute pressure in water surrounding the projectile, pounds per square foot

P_v = vapor pressure of water, pounds per square foot